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Report of the Terrestrial Bodies Science Working Group

Volume II. Mercury

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OVERLEAF: Mercury—The "Test" Planet

By virtue of its position nearest the Sun, Mercury becomes a crucial element in constraining and testing theoretical models for the formation of the solar system and its constituent members. Its surface records a lunarlike history, but its internal properties, revealed in the high planetary density and surface tectonic landforms, suggest a dramatically non-lunar interior. (Mariner 10 photomosaic of Mercury as viewed during the initial approach; JPL photograph P-14918A)

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PREFACE

This volume is one of a nine-volume series documenting the work of the NASA-sponsored Terrestrial Bodies Science Working Group in developing plans for the exploration of Mercury, Venus, the Moon, Mars, asteroids, Galilean Satellites, and comets during the period 1980-1990. Principal recommendations and conclusions are contained in Volume I (Executive Summary); reports and working papers of the study subgroups are presented in Volumes II-IX.

This volume is the report of the Mercury subgroup, whose members and contributors are A. L. Albee (chairman), F. V. Coroniti, M. C. Malin, and C. P. Sonett.

CONTENTS

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Figure

Tables

SECTION I

MERCURY SCIENCE OBJECTIVES AND RATIONALE

The level of knowledge of Mercury and its environment has passed through three phases during the past fifteen years. These periods - pre-1965, 1965-1974, and Mariner 10 (post-1974) -- will each be discussed in the following paragraphs.

The pre-1965 period of Mercurian studies consisted primarily of astronomical observations. From direct viewing of the planet's disk and studies of the effect of the planet on cometary orbits, the radius and mass were determined. From these observations came the single most important element in our pre-1965 knowledge of Mercury -- its high density (~5.5 gm/cm^3). Studies of faint albedo features on the planet's surface suggested synchronous rotation (i.e., a rotation rate about its spin axis equal to the revolution rate about the Sun ~88 days).

In 1965, radar observations showed that Mercury rotated more rapidly than previously believed, and theoretical analyses suggested it was in fact in a 3/2 spin-orbit resonance (i.e., it rotated three times about its spin axis every two revolutions about the Sun). Extensive re-evaluation of existing data and the acquisition of spectroscopic and more detailed radar data led to the conclusions that Mercury has (1) a lunarlike regolith, (2) lunarlike materials on its surface, (3) kilometer-scale relief with large craters, and (4) little or no atmosphere.

In 1974 and 1975 three flybys by Mariner 10 provided detailed observations of Mercury. Among the observations two were most important. First, Mercury displayed a remarkably lunarlike physiography with craters and smooth, marelike plains. Second, Mercury had a magnetic field, apparently dipolar, interpreted to be intrinsic. Although only one-half of the planet was seen, a host of surface observations showed subtle differences from lunar landforms, suggested that unique processes acted on Mercury. No compositional data was acquired by Mariner 10.

Our present understanding of Mercury is thus primarily based on astronomical observations and Mariner 10 spacecraft observations.

SECTION II

SUMMARY OF KNOWLEDGE CONCERNING MERCURY

A. IMAGING

1. Observations

Generally lunarlike surface morphology with many craters.

Three dominant terrain types: heavily cratered terrain, intercrater plains, and smooth plains.

Planetary dichotomy: incoming side is heavily cratered whereas outgoing side has smooth plains.

Unique landforms: a hilly and lineated terrain, approximately antipodal to the large Caloris basin, and large, arcuate escarpments.

Cratered terrain/plains display little albedo contrast as compared to the Moon.

Small color differences seen, most related to "fresh" rayed craters.

Distribution of crater ejecta is restricted relative to the Moon, which is consistent with higher gravitational acceleration.

Rotation rate = 58.661 ± 0.017 days (first Mercury encounter to second Mercury encounter).

Albedos:

Darkest = 0.11.

Smooth plains = 0.15 ± 0.02.

Intercrater plains = 0.15 ± 0.02.

Crater rays = 0.23 ± 0.03.

Brightest (bright craters) = 0.48.

2. Interpretations

Five-stage history: (1) accretion and early differentiation, (2) erosional "event" followed by discrete episode of terminal bombardment, (3) formation of the Caloris basin, (4) flooding of that basin and other areas, and (5) light cratering accumulated on smooth plains.

Intercrater plains represent a post-accretion, pre-"cataclysm" erosional/depositional period. Preservation of craters and rays suggests that there has been no atmosphere.

Intercrater and smooth plains are volcanic.

Crustal contraction formed compressional tectonic scarps.

Hilly and lineated terrain genetically linked to Caloris event.

B. INFRARED RADIOMETER

1. Observations and Calculations

Minimum temperature (measured near local midnight) ~100 K.

Minimum temperature (calculated for pre-dawn) ~90 K.

(observed for pre-dawn) ~110 K.

Thermal inertia (mean, incoming) = 1.7 x 10^{-3} cal cm^{-2} $sec^{1/2}$ K^{-1}.

Thermal inertia (mean, outgoing) = 2.5 x 10-3 cal cm^{-2} $sec^{-1/2}$ K^{-1}.

Local anomalous thermal inertia ~3 x 10^{-3} cal cm^{-2} $sec^{-1/2}$ K^{-1}.

2. Interpretations

Observations and calculations consistent with the presence of a layer of insulating silicate dust at least a few tens of centimeters thick similar to lunar regolith.

Spatial variations suggest large-scale regions of compacted soil or dust-free areas of boulders or bedrock outcrops.

C. ULTRAVIOLET SPECTROMETER AND AIRGLOW

1. Observations (Table 1)

2. Interpretations

If He is lost by thermal escape, the atmospheric residence time is 10^5 sec. The source strength required to maintain the observed He atmosphere is $10^7 cm^{-2} sec^{-1}$, comparable to the He source in the Earth's atmosphere.

Table 1. Upper Limits to the Abundances of Atmospheric Constituents on Mercury Deduced from the Ultraviolet Observations.

Probable emitting species	Channel, Å	Upper limit to limb brightness, rayleighs	g-value at Mercury, photon sec^{-1}, $atom^{-1}$	Vertical column density, cm^{-3}	Partial pressure, mbar
He^+	304	1200			
Background	430				
He	584	84	2.0×10^{-5}	7×10^{11}	2×10^{-12}
Ne	740	23	5.1×10^{-8}	3×10^{13}	4×10^{-10}
Ar	869	85	4.2×10^{-7}	1×10^{13}	3×10^{-10}
Ar	1048	150	1.4×10^{-6}	5×10^{12}	
H	1216	5000	1.5×10^{-2}	1×10^{11}	1×10^{-13}
O	1304	240	1.3×10^{-1}	1×10^{11}	2×10^{-12}
Xe(1470 Å)	1480	490	1.0×10^{-5}	1×10^{12}	1×10^{-10}
C	1657	870	1.4×10^{-3}	5×10^{10}	4×10^{-13}

The data were obtained on 29 March 1974 at 2028 GMT. The 0.13° field of view was 15 km above the bright limb at a range of 12,400 km. A temperature of 550 K was assumed in calculating the vertical column densities. These data are not corrected for background.

D. RADIO TRACKING

Radii: entry = 2400 ±2 km.
exit = 2438 ±2 km.

comparable to 2439 ±1 km (by radar).

Mass: 6,023,600 ±600 reciprocal solar mass.

Mean density: 5.44 gm/cm^3.

Gravity: J_2 ~60-90 x 10^{-6}.

(interpretation: Mercury is more oblate than hydrostatic).

Atmospheric pressure < 10^{-8} millibar.

E. SOLAR WIND INTERACTION

1. Observations

Global magnetic field with moment ~4 x 10^{-4} that of Earth's and orientation close to rotation axis.

Peak surface value ~2 x $10^3\gamma$.

Solar wind "stopped" by magnetosphere except possibly regionally over planet during solar storms.

Magnetosphere properties similar to Earth's but much weaker.

2. Interpretations

No clear understanding of field source -- remanence or dynamo?

F. INTERIOR

1. Observations

High mean density coupled with high cosmic Fe abundance indicates a high mean Fe content.

Surface features indicate presence of silicate crust and suggest that planetary differentiation has occurred.

Presence of magnetic field supports possibility of a core.

2. Interpretation

Infer presence of a Fe core, approximately 0.75-0.80 the radius of Mercury.

SECTION III

ORIGIN AND EVOLUTION OF MERCURY

Two important questions concerning the origin and evolution of Mercury have been raised by the Mariner 10 mission: what sequence of events resulted in the observed surface features? and how can the magnetic dipole field be explained? Mercury provides a test case for examining the mechanics, thermal evolution, and chemistry of small, dense planetary bodies in the near-Sun environment. Given the right data, it can be used to examine current theories of planetary accretion which predict composition trends as a function of position in the nebula, to understand the thermal evolution of small dense bodies, and to understand bombardment chronologies as a function of position in the solar system. These and many other basic problems require new compositional, geological, and geophysical data for their solution.

A Mercury orbiter would provide the capability for addressing a wide variety of planetology, atmosphere, magnetosphere, and solar physics problems:

(1) Planetary properties

What is the figure and mass distribution?

What is the gravity field?

Why is Mercury spin-orbit coupled?

(2) Magnetic investigations

What is the source of the magnetic field? Remanent? Dynamo?

How does thermal history affect planetary magnetization processes?

(3) Magnetospheric processes

What mechanism accelerates high-energy particles?

How does the absence of an ionosphere affect magnetospheric convection and dynamics?

What are the supply and loss rates for the Mercurian atmosphere?

(4) Atmospheric processes

Are volatiles being contributed by planetary outgassing?

What are the thermal, surface, and magnetospheric losses?

(5) Core properties

How large is the core?

Is the core convecting?

What is its composition and state?

(6) Chemical composition of the crust

How does the composition of the crust compare to the lunar and terrestrial crusts?

Does the crust have a uniform composition laterally and vertically?

How does the thickness of the crust vary?

How is the composition of the crust related to isostatic compensation?

(7) Crustal evolution

Was the crust produced by fractional crystallization of a global "magma ocean"?

How does the chemical composition inferred for Mercury compare to that predicted by current theories of planetary accretion?

What role did the large basins have in crustal evolution?

What is the physical setting in which the smooth plains were generated?

How is chemical composition of crustal units related to age of formation?

How did crustal strength vary with time?

(8) The thermal history of Mercury

What is the concentration of heat-producing elements?

What is the temperature profile of the Mercurian interior?

Is the deep interior presently heating or cooling?

When did the core form?

(9) Solar physics/relativity

Are neutrons produced in energetic particle trapping regions?

What nuclear processes occur during solar flares?

How oblate is the Sun?

Is the solar interior rapidly rotating?

What are the observational constraints for theories of gravitation?

SECTION IV

MEASUREMENTS REQUIRED FOR PRINCIPAL SCIENTIFIC OBJECTIVES

A. PLANETARY PROPERTIES

Knowledge of the detailed shape, topography, and mass distribution in a planet provides important insights into its nature and evolution. Mapping the gravity field helps to delineate the mass distribution; the gravity field taken in conjunction with the topography serves to indicate the strength of the planet; and the figure provides some measure of the paleogravity. Thus doppler and altimetry data provide important constraints on planetary properties.

B. MAGNETIC INVESTIGATIONS

On Earth, the surface remanent magnetism may be attributed to the dynamo field associated with Earth's core. This field has existed since very early in Earth's history. On the Moon, the surface magnetic field appears to be associated with relatively shallow crustal sources. Mercury presently possesses a dipole field capable of magnetizing the crust, but it is not known whether this field existed at the time of crustal formation. Substantial remanence is possible only at shallow depths due to presumably high subsurface temperatures. Thus major questions are: would the pattern of magnetization be Earth-analogous or resemble the lunar fields? What associations with surface features such as lava flows, rilles, scarps, craters, or ejecta blankets might exist? Would significant magnetization occur only at the low temperature poles?

Observation of remanent magnetism by magnetometers in a single orbiter would be unlikely since magnetospheric variations would overwhelm the surface fields at reasonable orbital altitudes. A lander could provide direct determination of surface field strength that would be unambiguous and free from problems of interpretation, but lacking in topographic coverage.

A secondary area of investigation that might be possible is determination of the higher-order magnetic multipole moments for the planet. If a particle and fields subsatellite were available for magnetospheric studies, the magnetometers on board two spacecraft could probably, under quiet solar wind conditions, distinguish the variations in the planetary field from magnetospheric current systems. The higher-order moments might then allow inferences concerning interior convection. However, significant understanding can be achieved by flying only a single magnetometer and establishing an accurate baseline value for the present dipole field. Future missions might then detect an alteration in planetary field strength due to secular changes in the magnetic field.

C. MAGNETOSPHERIC PROCESSES

The observations by Mariner 10 of the Mercurian magnetosphere have provoked considerable interest. A primary topic for investigation is the origin of the high-energy particle bursts: 100 to 300 keV electrons and protons have been reported, but controversy surrounds these observations. The presence of energetic electrons is beyond dispute. However, adiabatic acceleration does not account for the observed energies, and some other explanation is required to account for the data. Improved measurements including the pitch angle distribution of high-energy particles should aid in determining the acceleration mechanism. The lack of an ionosphere poses a problem for magnetospheric convection. Can field lines diffuse through the planetary interior at speeds typical of plasma flow velocities? If not, how are convection and substorms affected? Is the substorm triggering mechanism at Earth related to ionospheric resistivity, or will a comparison with the Mercurian magnetosphere argue for tail instability? What convection patterns occur in the absence of rotation? How does plasma enter and leave the magnetosphere, and what are the supply and loss rates for the planetary atmosphere?

These basic questions can be answered by the following instrumentation: a magnetometer, a plasma detector, and high-energy charged particle detectors. An orbit with a period of 6 to 24 hours and a low (60° or less) latitude periapsis is well suited for magnetospheric investigations; a circular orbit would be less desirable for this purpose. The dynamic response of the magnetosphere to changes in solar wind conditions could also be investigated if a particles and fields subsatellite provided simultaneous data at different locations in the solar wind and/or magnetosphere. A plasma wave experiment should be part of any such thorough magnetospheric study, although it has not been included in the studied baseline orbiter payload.

D. ATMOSPHERIC COMPOSITION

Hydrogen and helium have been detected in the Mercurian atmosphere by the ultraviolet spectrophotometer on board the Mariner 10 spacecraft. The amount of He in the atmosphere could be supplied entirely from the solar wind or might result in part from U and Th decay with consequent outgassing from portions of the planetary interior. The Mariner 10 experiment failed to detect any evidence for volatiles such as H_2O, CO_2, CO, Ne, or Ar in the planetary atmosphere. The absence of volatiles is in agreement with cosmochemical theories of solar system origin that predict low amounts of volatiles (including K) at Mercury's orbit; an alternative explanation may be that volatiles remain trapped in the crust.

An important issue is the origin of He in the Mercurian atmosphere. Improved limits or detection of solar wind Ne would characterize the supply and loss mechanisms for a gas solely of solar wind origin. Inferences for He origin would then be possible. Correlations of atmospheric He observations with tidal stress and simultaneous plasma detector measurements of solar wind He could determine the origin of atmospheric He. Detection of ^{40}Ar in the atmosphere could furnish evi-

dence for K in the planetary interior and its depth distribution. Detection or better limits for a variety of atomic species can be achieved at high altitudes by an ultraviolet spectrophotometer. At high altitudes (~500 km), a neutral mass spectrometer can detect H and He; at lower altitudes (~300 km), heavier species may be detected if present. A neutral mass spectrometer has the additional capabilities of determining isotope ratios and analyzing molecular compounds. Serious consideration should be given to the inclusion of a neutral mass spectrometer on a Mercury orbiter with a low periapsis altitude.

E. CORE PROPERTIES

The Mariner 10 observation of a planetary dipole magnetic field at Mercury strongly suggests the existence of a convecting core. This result and the estimated 80% core size imply differentiation of the whole planet. Core convection at Mercury poses interesting problems. The bulk composition of the planet is not expected to contain much K; and U and Th would presumably be differentiated upwards into the planetary crust. Could U be presently retained within an inhomogenously accreted planetary interior? Does a power source other than radioactivity power the dynamo? Is a dynamo compatible with the low rotation rate? What portion of the core is molten? In contrast to the Earth, where the inner core is solid, at Mercury there is some evidence that the outer core may be solid, as recent volcanism and plate tectonics might otherwise be expected. Insight into these questions will be provided by surface abundance maps of U and Th and by a heat flow measurement.

An accurate determination of core size could provide complementary inferences concerning the composition of the planetary crust. Such studies require a lander. Accurate measurement of planetary libration, in conjunction with the gravitational moments J_2 and C_{22} would answer a number of crucial questions, including whether the core is molten, and if so, what is the size of the molten portion of the core. Lander science (e.g., magnetometers used in concert with an orbital magnetometer, or seismometers) could perform equally important indications.

F. CRUSTAL COMPOSITION

The bulk density, in conjunction with the chemical composition and volume of the crust, place constraints on the bulk chemistry of Mercury. If the crustal volume and composition were known, the chemical composition of the whole planet might be estimated. Mercury, therefore, provides a new testing ground for cosmochemical models of solar system origin and theories of planetary evolution. Observations suggest that the Mercurian crust is differentiated; it must have a chemical complement at depth. The crust can be presumed to be composed of high-temperature minerals in analogy to the plagioclase-rich composition of the lunar crust. However, little is known of the chemical composition, the uniformity in structure, the thickness, and the minerals that might be present. This state of ignorance can be attacked through the combination of gravity, altimetry, geochemical, and multispectral data

obtained by an orbiter. Surface chemistry obtained by X-ray fluorescence and γ-ray emission may reflect the underlying crustal composition. Geochemical and multispectral data will indicate lateral variations in surface composition and may provide the basis for estimating vertical variations. Implications of surface composition for crustal composition are aided by gravity data, since the density implied by surface composition and mineralogy allows the gravitational effects of a crust of an assumed thickness to be modeled. Variations in crustal thickness determined by altimeter and doppler data could be compared to possible differences that might exist between the locations of the center of figure and the center of mass. Finally, the average global heat flow can provide a strong constraint upon the bulk planetary composition which in turn constrains the crustal composition.

G. CRUSTAL EVOLUTION

Mercury allows a glimpse of the early stages of planetary crustal evolution unaffected by plate tectonics or eolian and aqueous erosion. The photogeological investigations made possible by Mariner 10 reveal a lunarlike landscape but with significant differences. An analogy can be drawn between heavily cratered terrain on Mercury and the cratered lunar highlands, between the smooth plains and mare regions and between intercrater plains on Mercury and highland plains (light plains) on the Moon. Even this analogy is uncertain: orbiter data could verify that the smooth plain regions are indeed volcanic flows rather than impact-generated debris. Other significant clues to planetary history are the compressional features such as lobate scarps and the distribution of craters over the planetary surface. Finally, and most important, over half the planet has not been observed. Substantial changes in our understanding of both the Moon and Mars resulted from more complete photographic coverage. Similar alterations in our knowledge of Mercury will undoubtedly result from completing the photographic reconnaissance of that planet.

One aspect of crustal evolution is the interplay of tectonic and igneous processes. For the earlier stages of crustal evolution we can ask about relationships between crustal composition and crustal thickness. Is the crust uniform in thickness? Are crustal variations in thickness isostatically compensated in the planetary interior? The primordial planetary crust was heavily cratered. How did this affect the course of crustal formation? How severely has cratering altered the original features produced during the formation of the crust? Was there a late period of cataclysmic increase in cratering rate as has been suggested for the Moon?

The spatial relationships of volcanic rocks to crustal structure are crucial to providing a better definition of the physical settings in which basaltic rocks were generated. On Earth, certain igneous rock types tend to be related to tectonic environments. Are there similar associations with craters, basins, and scarps on Mercury? What chronology for the formation of chemically different volcanic units may be estimated from photogeologic determinations of age?

The composition, distribution, topographic, and isostatic information necessary to address these questions can be obtained by doppler tracking, altimeter, γ-ray, X-ray, multispectral imager, and infrared spectral data.

Further powerful investigation techniques would be feasible with lander experiments. Magnetometers and seismometers could probe the planetary interior. Seismic velocities and conductivities would allow the subsurface density, structure, and thermal profile to be inferred. Imaging could allow characterization of small-scale surface, and α-particle or γ-ray analysers could provide data on detailed chemical and elemental compositions.

H. THERMAL HISTORY

What is known of the planetary thermal history? Two significant clues are available: the possible existence of a molten core and the surface compression features. The existence of a core indicates differentiation has occurred, and its molten state sets constraints on the present interior temperature. The surface compression features indicate either expansion of a crustal layer or contraction of the interior under a crustal layer. Further information is required to better define the planetary thermal history.

The most significant factor in determining the planetary temperature profile is the quantity and distribution of radioactive elements. The total planetary heat flux may be used to fix the content of radioactive elements if the planet is in a steady state, while surface γ-ray data measures the crustal abundances. With this information, a useful model of the thermal history should be possible.

Interior electrical conductivity data obtained by lander and orbiter magnetometers could be interpreted in terms of thermal and compositional variations. The temperature of the planetary core would depend significantly upon the amount of radioactive elements retained in the planetary interior. For all these reasons, a heat flux experiment, if feasible, should be part of a Mercury orbiter payload.

I. SOLAR PHYSICS/RELATIVITY

The two areas of interest are (1) solar neutron observations, and (2) spacecraft tracking to determine solar J_2 and relativity parameters.

1. Solar Neutron Observations

Solar neutron measurements cannot be obtained at Earth orbit (except for energies greater than 50 MeV) because lower energy neutrons decay before reaching distances of 1 AU. Two solar neutron components may be identified: (1) quasi-steady production which, though primarily from extensive areas of solar activity, also may extend to lower levels over the local photosphere, and (2) impulsive neutron production from

solar flares associated with collisions between accelerated charged particles and the chromospheric and coronal material. Quasi-steady production of neutrons would be expected if a magnetic trapping region in the solar corona maintains a supply of solar cosmic rays in the corona that can cause nuclear reactions. The alternative possibility is escape of solar cosmic rays from the corona immediately after acceleration. Impulsive neutron production during solar flares due to acceleration of energetic particles and consequent nuclear reactions is not well understood; little is known of the acceleration mechanism or the duration and direction of energetic particle bursts. Detection of solar neutrons would provide information concerning time dependence and directionality of nuclear reactions in the solar atmosphere that cannot be obtained from gamma ray spectroscopy. A neutron spectroscopy experiment might be the missing link in explaining puzzles such as the super enrichment of the He^3 (amounts comparable to He^4) that occurs during solar flares.

A substantial argument for including a neutron spectrometer on a Mercury orbiter is the possibility of using Mercury as a shutter for solar neutrons. Neutron emission from the spacecraft due to nuclear reaction with solar cosmic rays will cause an increase in background as distance to the Sun decreases; Mercury occultation allows this background to be directly measured and removed from the data. In addition, a solar probe mission would spend a relatively short time in the vicinity of the Sun (perhaps 30 days in transit from 1 AU to 4 $R_\odot$); during this period no substantial flare might occur. A one-year Mercury orbiter mission would offer improved opportunities for detection of neutron emission from solar flares. Finally, as RTG's will be required on a solar probe (gravitational deflection from Jupiter is required), neutron background from the RTG's will almost certainly prevent a neutron spectrometry experiment from being included on a solar probe.

2. Spacecraft Tracking

Accurate spacecraft tracking can provide important constraints for non-Newtonian metric gravitational theories and upon estimates of the rotation rate of the solar interior. Corrections to the Keplerian motion of a single planet around the Sun include the parameterized post-Newtonian theory parameters β, γ, α_1, α_2, α_3, and Sw as well as corrections due to the solar quadruple movement J_2 and a possible secular change in the gravitational constant G. Thus, accurate Earth-Mercury measurements over an extended period would provide constraints on these corrections. Perihelion advance, in effect, determines a combination of the metric parameter β with solar J_2, while advance of the node permits solar J_2 to be measured separately. An accurate value of the parameter β can be obtained with dual-frequency time delay measurements near the Sun. Mission requirements for such measurements have been studied by the Working Group Subpanel on Relativity and Gravitation for Shuttle Astronomy (1976) and by Wahr and Bender (1976).

SECTION V

MISSION CONCEPTS AND SCIENCE PAYLOAD

In this section are brief descriptions of experiments and/or instruments forming a possible baseline science payload of a Mercury orbiter. It draws heavily on the Lunar Polar Orbiter baseline payload, but several additional experiments have been added to augment the payload to investigate atmospheric, magnetospheric and solar physics phenomena. Table 2 summarizes the payload description.

As indicated in the previous sections, both a subsatellite and a "simple" lander would add substantially to the results of a Mercury orbiter and might be the only way to answer some key questions. At this stage of planning, both a lander and a subsatellite must be considered as science instruments that could displace in terms of scientific return some of the instruments listed in the orbiter baseline payload.

A radio tracking experiment can be used to determine the Mercurian gravity field. Both low- and high-frequency variations will be extracted from doppler radio tracking of the orbiting spacecraft. The low-frequency determinations will provide global information on the larger-scale structure of Mercury, while the high-frequency parameters will describe the surface mass distribution in relation to topography. The use of dual-frequency transponders should be considered for increased reliability of tracking data. In conjunction with altimetry data, the local and global isostatic conditions can be determined with consequent implications for the viscous and thermal state over geologic time. A parameter depending upon correlated values of solar J_2 and the relativistic PPN parameter β can also be measured on a mission of one-year duration.

The altimeter measures height above the surface by reflection of radio or light waves from the planetary surface. The measured altitude is valuable for photogeologic studies and determination of planetary shape. When combined with doppler gravity data, the altimeter data can be used for studies of local and global isostasy.

The magnetometer measures the magnetic field of Mercury and of the surrounding solar wind and magnetosphere environments. High background levels due to magnetospheric variations will likely be sufficiently large at the probable orbiting level to prevent detection and observation of localized remanent field regions.

Particle detectors are provided for measurement of the high-energy charged particle fluxes in the Mercurian magnetosphere. A typical set of detectors that might be provided would consist of a proton-alpha particle detector covering the range 50 keV to 60 MeV per nucleon, an energetic electron detector for the energy range 30 keV to 1 MeV, and a proton detector for greater than 40 keV.

The plasma detector measures electron and positive ion fluxes in the energy range 10 eV to 20 keV, and thereby determines the velocity

Table 2. Mercury Orbiter Baseline Science Payload

Instrument	Mass kg	Power w	Data rate, bps	Pointing	Size, cm	Comment
Gravity/doppler tracking	-	-	-	-	-	Ideal experiment
Altimeter	10	22	100	Nadir	Ant: 60 dia Elect: 30 x 30 x 30	LPO derivative
Magnetometer	6	3	300	Omni	Detector: 7 x 7 x 7 Elect: 15 x 15 x 10	LPO derivative
Particles	9	10	400	(see below)		
High-energy	4	5	100	Omni	20 x 20 x 15	High-energy experiment in addition to LPO pay-
plasma	5	5	300	Nadir + Zenith	24 x 24 x 10	load LPO derivative
Solar neutron detector	20	5	50	Solar	Detector: 20 x 20 x 40 Elect: 20 x 20 x 25	Boom-mounted solar physics experiment
Heat flow	15	12	120	(see below)		
Microwave Radiometer	10	10	100	Nadir	60 x 60 x 15	LPO derivative
Thermal IR	5	2	20	Nadir	5 x 8 x 20	
γ-ray spectrometer	10	8	3000	Nadir	30 dia x 40	LPO derivative
X-ray spectrometer	12	8	300	Nadir + Sun	25 x 25 x 30 + 30 x 10 x 20	LPO derivative
Compositional IR	10	7	10,000	Nadir	10 x 10 x 30	LPO derivative
High-resolution spectral mapper	5	7	65,000	Nadir	10 x 10 x 30	LPO + framing capability
Ultraviolet-spectrophotometer	4	2	200	Limb	4 x 4 x 13	Mariner 10 derivative
Neutral mass spectrometer	5	7	8	Velocity vector	Detector: 8 x 15 x 18 Elect: 11 x 14 x 22	LPO derivative
Totals	106	91	79,500			

and density of plasma flows in the Mercurian magnetosphere. Information concerning particle acceleration and drifts in the magnetosphere can be obtained at higher energies. Detection of possible local remanent magnetism by reflection of electrons from surface field regions may be feasible at low altitudes on plasma sheet or solar-wind-connected field lines.

The solar neutron detector would measure the energy of solar neutrons emitted in the range 10 keV to 50 MeV and thereby determine the possible steady-state production in magnetic trapping regions and the characteristics of flare-accelerated high-energy particle bursts.

The microwave radiometer measures microwave emission from the planetary surface at several wavelengths. The emission at different wavelengths is dependent upon surface brightness, temperature as a function of depth, and the electrical and thermal conductivity of the surface material. Microwave radiometer and thermal infrared radiometer data are interpreted in terms of surface temperature, temperature gradient, heat flux, and the electrical and thermal properties of surface material.

The thermal infrared radiometer measures infrared radiation from the surface of Mercury in the range of 5 to 20 μm. Data is interpreted to determine the surface temperature of the planet. In combination with microwave radiometer data, the temperature gradient, heat flux, and electrical and thermal conductivities of the surface can be determined.

The gamma ray spectrometer measures the energy of gamma rays in the range 0.5 to 10 MeV by use of a cooled intrinsic Ge detector. Natural radioactive decay allows direct measurement of Th, K, and U abundance on the planetary surface, while processes due to cosmic rays and high-energy solar particles produce gamma ray lines for the elements H, O, C, S, Na, Al, Si, Ti, and Fe. Gamma ray bursts from galactic sources and solar flares can also be detected.

The X-ray spectrometer measures the energy of X-rays emitted from the Mercurian surface due to fluorescence caused by solar X-ray emission and energetic particle bombardment; direct solar emission and hard X-ray bursts from galactic sources can also be detected. Results are interpreted to measure the surface abundance of Mg, Al, Si, K, Ca, and Fe. A calibration card viewed by an X-ray detector is exposed to the Sun so that temporal variations in solar X-ray emission can be monitored.

The composition infrared spectrometer measures numerous narrow spectral wavelengths between 0.3 and 2.5 μm, providing details of the reflected continuum and absorption characteristics of the surface materials. Mineral phases can be identified and certain elemental abundances inferred.

The high resolution spectral imager acquires data in several spectral bandpasses over a large spacial area and displays this data in image form. It provides large-area compositional maps used to generalize

the detailed compositional studies of γ-ray and X-ray spectrometers and compositional infrared spectrometers. It may also acquire high-resolution monochromatic and/or moderate-resolution stereoscopic images for morphologic studies.

The ultraviolet spectrometers measure UV airglow (atmospheric fluorescence due to solar UV emission) and solar occultation UV flux to determine the composition of the Mercurian atmosphere. Additionally, the surface UV albedo can be measured. Atomic species such as H, He, O, Xe, Ar, Ne, and molecular CO could be observed or more stringent limits on atmospheric densities established. Limits on compounds such as H_2O and CO_2 could be derived from UV airglow measurements of the photodissociation products H, O and CO.

The neutral mass spectrometer measures in situ concentrations of neutral atmospheric species, particularly H_2, He, Ne, Ar, CH_4, and CO_2. Neutral particles which enter the analyzer aperture are ionized by an electron beam, are accelerated, and then sorted according to mass to charge ratio.

A "simple" lander and/or a subsatellite would significantly augment the science return from a Mercury orbiter. The primary goal for a Mercury mission considering our present knowledge is to determine its internal structure and state. It is difficult to attain this goal using only a single orbiter. Even a simple lander might have a seismometer to determine the presence or absence of seismicity, or a gravimeter or a magnetometer to measure fields at the Mercurian surface, or a transponder or some other instrument to permit measurement of the librations. Such measurements in conjunction with those from the orbiter, could provide more positive information on Mercury's interior. Similarly, a simple subsatellite in a larger orbit with a magnetometer and particles and fields experiments would greatly enhance our understanding of the magnetic field and its interaction with the solar wind.

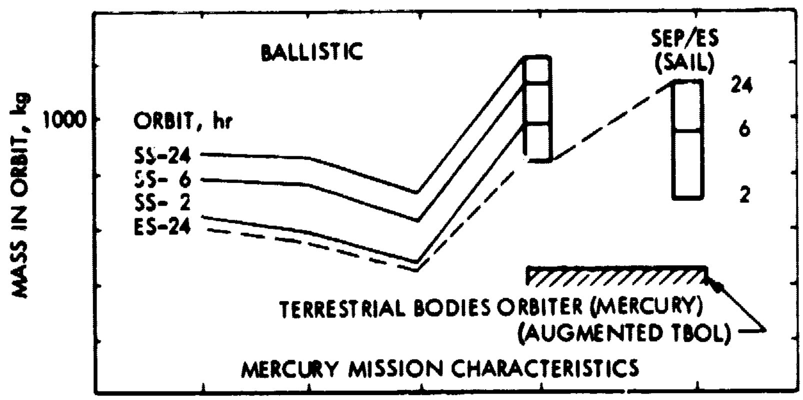
SECTION VI

MISSION CONSTRAINTS AND DEVELOPMENT REQUIREMENTS

A recent (June 1976) Mercury Orbiter Mission Study at JPL has identified and discussed in detail a number of propulsion and thermal requirements that make it difficult to achieve the circular low-altitude orbit that would be required to fully meet the scientific objectives. Subsequently (August 1976), these were modified by a systematic search for ballistic trajectories using Venus flybys (Bender, 1976). Figure 1 summarizes some of the relationships between propulsion requirements, orbital characteristics, mass in orbit, and thermal effects due to solar radiation reflected from Mercury. The dashed line correlates the weight that would be placed in 24-hour orbit using Earth-storable propulsion for various ballistic opportunities and for SEP or Solar Sail in post-1984. A March 1983 ballistic mission with space-storable propulsion and Venus gravity-assist could place an augmented Terrestrial Bodies Orbiter (Lunar) (TBOL) science payload into 6-hour orbit with a margin possibly sufficient for a simple lander or subsatellite. However, the orbit would be elliptical, 500 x 7400 km, with a periapsis near the north pole, and the data sets would be degraded by poor southern hemisphere coverage, cyclic lighting conditions, highly varied resolution due to variation in altitude, etc. Even double missions in March and July 1983 with periapses in different hemispheres would not meet science objectives fully.

The requirements for the post-1984 mission shown on Figure 1 are typical for a mission using a low-thrust propulsion system such as solar electric propulsion (SEP) or solar sails (SAIL). Such a mission would provide good orbital science from a circular orbit, with sufficient mass margin for temperature control and for a simple lander and/or subsatellite. An even lower altitude would be desirable and might be achieved as development proceeds and the net mass becomes better determined. A similar mission could be launched ballistically in July 1986, but would have a long flight time.

Even a ballistic mission to Mercury requires development of propulsion systems and, as indicated above, a good orbital science mission requires development of a low-thrust propulsion system (SEP, SAIL, or both combined). Temperature control requires development work on both active and passive cooling systems. Most of the orbital instruments do not require an active development program specifically for a Mercury mission, since we can expect continued development benefiting from other terrestrial planet orbiter experiences. An active program for developing simple "rough" lander packets for planets with little or no atmosphere seems very important. Theoretical studies of dynamos, magnetospheres, and other topics have not yet caught up with the available data. Hence, such studies need continued support so that the measurements can be designed to test the best possible theory or theories.



DATE	7/81	3/83	7/83	7/86	POST 84
FLIGHT, days	1066	986	943	1243	550

MERCURY ORBITAL CHARACTERISTICS

PERIOD, hr	ALTITUDE, km	TEMPERATURE, °C
24	500 × 128,000	20-40
6	500 × 7,400	30-50
1.9	500 CIRCULAR	90-130
1.4	100 CIRCULAR	VERY VERY HIGH

Figure 1. Relationship of Propulsion Requirements, Orbital Characteristics, Mass in Orbit, and Thermal Effects for a Mercury Orbiter

SECTION VII

CONCLUSION AND RECOMMENDATIONS

We recommend that a Mercury mission be scheduled to make use of low-thrust propulsion systems in order to achieve maximum scientific return and in order to permit completion of the "reconnaissance" phase of Mercury exploration in a single mission. We therefore recommend accelerated development work on solar electric propulsion (SEP), solar sails (SAIL), passive and active cooling mechanisms, and simple "rough landers".

BIBLIOGRAPHY

Bender, D. F., "Ballistic trajectories for Mercury Orbiter Missions using optimal Venus Flybys, a systematic search," AIAA/AAS Astrodynamics Conference, San Diego, Calif., August 1976.

"Mariner 10 Preliminary Science Reports," Science 185, 141-180, 1974.

"Mariner 10 Imaging Science Final Report," J. Geophys. Res., 80, 2341-2514, 1975.

Wahr, J. M., and Bender, D. L. (in press) "Determination of PPN Parameters from Earth-Mercury distance measurements."